Research Article

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Enhancement of heat transfer from solar thermal collector using nanofluid

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Abstract: Global energy consumption is increasing due to population growth and with it the adverse impact of fossil fuels on the environment, making it necessary to use renewable energy sources and convert them to electrical energy using different technologies. However, the solar energy potential remains unused, while it has numerous advantages, including as a source of clean electricity and heat. One of the main difficulties in energy-saving and compacted design is how to increase the heat transfer of solar equipment. As an innovative approach to enhancing fluids' heat transfer performance, some of the most active techniques are to exchange the working fluid with nanofluids. This work attempted to demonstrate heat transfer behavior changes when using nickel oxide (NiO), aluminum oxide (Al_2O_3), and copper oxide (CuO) as nanofluids at concentration volumes of 0.05, 0.075, and 0.1%. For this goal, a conical solar collector was built using local public steel sheets. Insulating polyurethane foam padding is used inside the cone. The sun's energy is focused on the absorbing surface using thin reflective aluminum foil. The study also includes a literature review showing how nanofluids can improve heat transfer in solar collectors. The results showed that adding nanoparticles can increase the rate of heat transfer and CuO nanofluids have better augmentation in heat transfer than Al_2O_3 or NiO-water nanofluids where 1% CuO nanofluids increases the efficiency by up to 7% compared to water.

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1 Introduction

Solar energy is a sustainable and clean energy source, and the global request for solar energy has augmented due to the desire to decrease the emissions of greenhouse gas. On the other hand, solar power generation using solar cells has little energy conversion efficiency; and as the cell temperature increases, the electrical energy efficiency also decreases [1]. Another application of solar energy is to obtain distilled water by evaporating and condensing brine [2]. Additional applications of nanofluid in the factories include the cooling of heat-producing elements in electronic elements [3], mini channel, microchannel, and nanochannel [4] thermal storage elements [5–7], and medical application exchangers [8]. A photovoltaic thermal (PVT) system is proposed that combines photovoltaic (PV) modules and solar thermal collectors that circulate a liquid to decrease the temperature of the photovoltaic cell while generating heat and electricity. Merging these two systems has the advantage of minimizing the installation area linked to installing PV modules and solar collectors individually. Since the 1970s, a great deal of research into PVT technology has been carried out, which has resulted in many international breakthroughs. Also, a smart control system can be applied to manage the signals and save the power using dynamic source routing protocol and different applications [9,10].

Working fluids used in most solar systems include water, air, glycols, and nanofluids. The highest level of efficiency that can be achieved in standing systems is restricted by the low thermal conductivity of these working fluids. Thus, there is a necessity to improve the heat transfer characteristics of working fluids to increase the efficiency of solar energy systems. Nanofluids have been shown to be useful as working fluids (and have excellent heat transfer properties). Solar energy has the potential to protect our planet from climate change as we rely on fossil fuels for our energy needs. Therefore, improving the efficiency of solar technology is crucial. Today, solar PV has proven to be competitive with fossil fuels. However, the temperature rises of solar cells, which affects their electrical efficiency, is a big concern. So, researchers developed a different way to eliminate additional heat from these devices and use nanotechnology to lower their temperature to increase their electrical efficiency. Nanotechnology is a multidisciplinary field that brings together engineering, science, and knowledge of microscopic scale. Nanotechnology can be used for various applications, including materials science, biology, and engineering. Nanotechnology can play an active role in solar energy by substituting working media with nanofluids. Nanofluids are heat transfer fluids that could allow the solar system to emit more heat [11].

1.1 Conceptual framework of nanofluid

Nanofluid definition. In the literature, nanofluids are defined in various ways. Still, most academics approve that it is a mixture of nanoparticles ranging from 1 to 100 nm in diameter that can be effectively dispersed in a base liquid. Water, refrigerant, glycol, or heat transfer oil can be used as the base fluid. Heat transfer through fluids in addition to the thermal performance of the overall system can be improved by using nanofluids [12].

1.1.1 Advantages and drawbacks

There are some advantages and drawbacks to the nanofluids:

(a) **Advantages**

i. Increase the density and specific heat product of the working fluid to increase its heat transfer coefficient.
ii. Increase the density and specific heat product of the working medium to transfer a large amount of thermal energy.
iii. Increase the heat transfer between the liquid and the receiver.
iv. Improve the electrical and thermal efficiency of photovoltaic systems.
v. Reduce the absorber temperature, thereby protecting the material.

(b) **Challenges**

Though nanofluids improve heat transfer, there are some barriers to their adoption, including:

i. A generation. Manufacturing and preparation costs are high.
ii. The use of nanofluids leads to high operating costs due to increased pumping work.
iii. If the system is operated under natural convection and carried too high temperatures, the nanoparticles will aggregate and behave unstable.
iv. Nanoparticles can attack and corrode metal parts of the system and even block flow paths. Corrosion depends on the material of the pipe. For example, even with water or nanofluids, corruption does not occur when using stainless steel tubes, but corrosion is evenly distributed throughout the pipe when using copper tubes.
v. Many authors believe that nanoparticles can have detrimental consequences on the environment and human health.

1.2 Heat transfer enactment using nanofluid

The use of nanofluidic technology to replace traditional liquids in today's solar panels is seen as a promising area for improved performance. However, nanofluids have some restrictions, such as corrosion of components, pump performance issues, pressure loss, and significant cost, to name a few. In the laminar flow regime, the pressure drop was increased by using copper oxide (CuO) oil-based nanofluid; in the turbulent power, the pressure drop was increased by increasing the volume concentration of TiO_2-water-based nanofluid. Therefore, selecting suitable nanofluids is crucial for optimizing the performance of solar panels. Due to its high-volume concentration, the viscosity of nanofluids needs to be higher. Nanofluids can be used in solar cells, solar thermoelectric cells, solar cooling systems, solar absorption cooling systems, and various other solar devices. Multiple authors have performed many tests on solar panels using water and nanofluids, and the results show that nanofluids in solar panels can improve heat transfer rates [13].

1.3 Solar thermal collectors

Solar energy remains the most abundant and limitless energy source on Earth. Various methods can be used to harness this energy, including solar panels Solar thermal collectors are systems that can use solar energy for heating and cooling. A heat transfer fluid is used in these collectors to direct the collected solar radiation where it is needed. Scientists have proposed various collector designs and improved collector materials to increase the conversion efficiency of solar panels. Solar collectors convert solar energy into the internal energy of a liquid medium. Due to their simple structure and low cost, solar panels are a viable heating solution for buildings and industrial applications. A solar collector is usually an essential part of any solar thermal system; it receives sunlight and converts it into heat energy.

Rooftop solar collectors are 60–70% efficient and are used to disperse solar thermal energy in buildings. Solar thermal energy can also be used to generate electricity in various industrial situations. It turns out that solar thermal power is cheaper than photovoltaic cells.

2 Review of related studies

Omisanya et al. [14] presented multiple studies showing that the addition of nanofluids can significantly increase the efficiency of solar panels, with thermal conductivity up to 160% and reductions in greenhouse gases such as carbon dioxide. Nanoparticles like aluminum oxide (Al_2O_3), mixed ZnO added to Al_2O_3, and metal particles (aluminum and copper) are dispersed in base fluid-like H_2O, glycerol, and biological fluids to produce nanofluids. The fluid viscosity, rate of absorption, coefficient of convective heat transfer, and heat loss were all improved by adding nanoparticles. The performance of many types of nanofluids in the kinds of solar collectors, such as flat plate, parabolic trough, evacuated tube, and direct absorption, is described in detail. Furthermore, the study sheds light on coming trends and issues (including toxicity). In spite of their toxicity, investigators are increasingly interested in using nanofluids in solar panels because of their excellent environmental properties and are exploring hybrid nanofluids to improve solar panels. Different nanofluids at different concentrations can also be used to tune solar panels.

Anbarsooz et al. [15] improved the heat transfer rate of solar collectors, which is critical to minimize system size. However, many methods of increasing the heat transfer rate from the absorber to the heat transfer fluid have been proposed in the literature. The most important ways are using vacuum receivers, adding vortex generators/turbulators, and using various nanofluids as heat transfer fluids. This study explores progress in improving heat transfer in solar collectors by using different nanofluids. According to the survey, Al_2O_3 and carbon nanotubes are the most commonly used nanoparticles, while water is the most widely used base fluid. Most studies have been performed on indirect solar panels; however, researchers have recently focused on direct absorption techniques. The thermal conductivity of the working fluid is critical in indirect absorption collectors, while optical properties are essential in natural absorption collectors. Therefore, for solar collector applications, optimization of the visual and thermophysical properties of the nanofluid is recommended. Wole-Osho et al. [16] discussed the effect of nanomaterials on the overall performance of solar collectors. The article also addresses the restrictions of using nanofluids in solar collectors and the difficulties. Most solar panels use nanofluids to improve the overall efficiency; however, until some issues related to nanofluids stability, and general probability are addressed, the promise of nanofluids in heat transfer applications cannot be achieved. Nagarajan et al. [17] explained the effects of nanofluids which are nascent liquids with thermal properties far superior to traditional fluids. Nanofluids can attain the maximum thermal performance at the lowest possible concentration through the uniform dispersion and stable suspension of nanoparticles in the bulk liquid. Nanofluids are used in various thermal applications, including automobiles, and power generation. Improving heat transfer in solar collectors is the most critical challenge in energy savings, compact design, and many operating temperatures. In this work, the literature on its thermophysical properties and the use of solar collectors with nanofluids is collected and evaluated. The conventional heat transfer using nanofluids and their special applications in solar panels have been described in recent literature.

Sopain et al. [18] using nanofluids for cooling, which is becoming increasingly important in various industrial applications. Compared with conventional fluids, nanofluids improve the heat transfer rate, optical properties, thermal properties, efficiency, and transmission and extinction coefficients of solar systems. The effect of different nanofluids on the cooling speed and the efficiency of the solar system had been investigated experimentally. For this reason, this review article discusses the impact of nanofluids on the efficiency and environmental benefits of the system. According to literature reviews, many researchers have explored the potential of nanofluids to cool various solar panels. This study also outlines the performance studies of solar collectors using nanofluids as working mediums, such as flat plate collectors and direct solar absorption collectors. The effect of surface area to volume ratio on thermal conductivity is greater than that of nanoparticle surface area. Ghasemi and Mehdizadeh Ahangar [19] compared the traditional parabolic collectors with nanofluid-based collectors, evaluating the temperature field, thermal efficiency, and average outlet temperature, while studying the effects of numerous factors for example the velocity of fluid, nanoparticles, volume fractions and concentration ratios etc. They concluded that adding trace amounts of copper nanoparticles to the base fluid significantly improved the endothermic capacity. They found that thermal and optical efficiencies and higher exit temperatures could be improved during the investigation, and the effects of concentration ratio, the volume percent of nanoparticles, and collector length could be investigated. Therefore, nanofluid-based parabolic concentrators outperform conventional collectors in terms of efficiency. With new options, Sharma and Kundan [20] conducted an experimental study of nanofluid-based concentrating parabolic solar panels. They investigated the conclusion of Al and CuO nanoparticles in H_2O as the working medium in an experimental parabolic solar collector. Mass flow rates were 60, 40, and 20 L/h, and a volume concentration of 0.01% nanoparticles was investigated, with nanoparticles ranging in size from 20 to 30 nm. In addition, they compared water/alumina nanofluids with CuO nanofluids and found that using copper oxide nanofluids as working fluids could improve overall efficiency of the system. Li et al. [21] used vigorous stirring and ultrasonic dispersion to prepare nanofluids enclosing aluminum oxide, zinc oxide, and magnesium oxide nanoparticles with condensed water as the base fluid. The forced convection heat transfer performance of the as-prepared nanofluids was investigated in a tubular solar collector. In the experiments, the heat transfer efficiencies of oxide, zinc oxide, and magnesium oxide nanoparticles were higher than in distilled water. The temperature difference between the nanofluid and distilled water is 1.0% by volume. Aluminum oxide, zinc oxide, and magnesium oxide nanoparticles can all reach 3°C in a day–night cycle. During the day, from 6:00 am to 6:00 pm, the maximum temperature difference between nanofluid and distilled water occurs around 10:00 am, while the maximum temperature between nanofluid and distilled water is around 3:00 pm. The nighttime temperature of the nanofluid was more than 1°C, higher than that of distilled water, suggesting that the nanofluid can store more thermal energy. The viscosity and heat transfer efficiency increased with the increase the Zinc oxide nanofluid concentration. Also, at 0.2 vol%, the temperature modification between zinc oxide nanofluid and pure water can reach up to 2.55°C concentration of 0.2% by volume. Concentrated zinc oxide nanofluids are attractive options for solar energy consumption due to their low viscosity and excellent heat transfer capability.

In this article, the concentrations of different types of nanoparticles throughout the conical solar collector were examined. The nanofluids were nickel oxide (NiO), Al_2O_3, and CuO with 0.05, 0.075, and 1% for each type. These types were selected according to the good thermal conductivity compared with other types especially since there is no comparison study mentioned between those types for the same system of the solar collectors.

3 Experimental setup

The schematic diagram of the experimental work is depicted in Figure 1. The key characteristics of the conical solar collector are as follows. The collector consists of a conical concentrator with a tracking system, a cylindrical absorber, a flexible core water pipe, and a data logger device. The system was built in an open space to make the most of the sunlight. The truncated cones are steel and supported by a structural frame that allows movement. A truncated cone-shaped collector is used to concentrate sunlight. An integrated structure of tiny conical and cylindrical tubes forms the absorbing surface. The diameter of the dish was 90 cm and the receiver diameter was 10 cm with 25 cm in length. The height of the dish from the ground was 100–125 cm to prevent any effect of the ground heat on the dish temperature.

A Type K TP-01 thermometer recorder was connected to record the temperature and TC-920 thermometer calibrator was used to calibrate the thermocouples. The calibrated curvature of thermocouple readings is shown in Figure 2, which yields an error of 2.80%.

3.1 Nanoparticle selection

Nanoparticles of NiO, Al_2O_3, and CuO were mixed with a base fluid to prepare a nanofluid. These nano particles was chosen for its high thermal conductivity, low cost, and chemical inertness for use as the base fluid. The nanoparticles were added to the main fluid and stirred well. Volume fractions of 0.05, 0.075, and 0.1% were used to prepare the nanofluids.

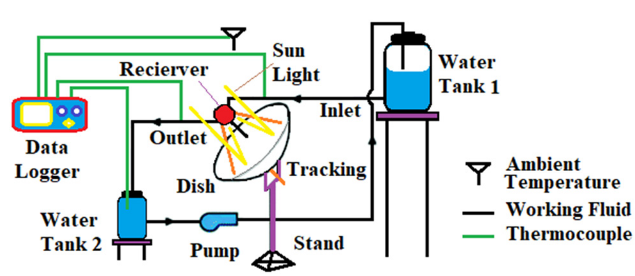

Figure 1: Schematic diagram of the experimental work.

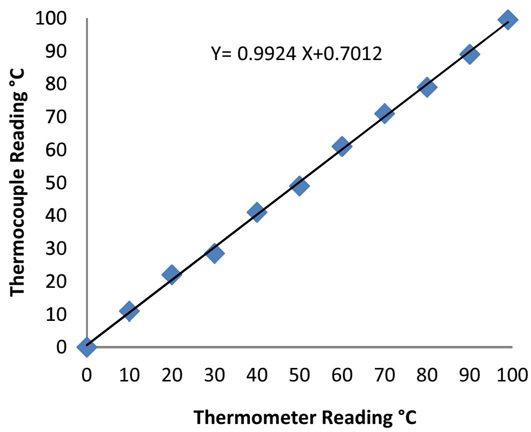

Figure 2: Calibration curve of thermocouple reading.

3.2 Operational methodology

The cylindrical absorber is filled with nano-liquid, and the water is circulated inside the receiver using a spiral copper tube, as presented in Figure 3. The water mass flow was kept constant at 8.33×10^{-3} kg/s and a 1.3 L absorber was filled with nanofluid, while the entire experimental setup was kept in an open area for solar radiation. The photons are bound by the collector and directed to the absorber. Thermocouples are used to record the temperature.

3.3 Preparation of nanofluid

Nanofluids were prepared using the method described by Sallal et al. [22] as a two-stage process. First, the required weight of the nanoparticles were measured using digital sensitive balance and then the nanoparticles were mixed with distilled water. The prepared dry nano powders were organized in three different base liquids (distilled water), as shown in Figure 3, and at three different volume fraction concentrations (0.1, 0.075, and 0.05%). The volume of the nanoparticle was compared to the base liquid defined by

$$\varphi = V_p/V_t. \quad (1)$$

In addition, nanoparticles mass was defined by

$$m_p = 1 \times 10^{-3}\varphi\rho_p. \quad (2)$$

And nanofluid density by

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_p.\ \rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_p \quad (3)$$

And nanofluid heat capacity by [11]

$$C_{pnf} = \frac{\varphi\rho_p C_{pp} + (1-\varphi)\rho_f C_{pf}}{\rho_{nf}}. \quad (4)$$

The features of pure water and NiO, Al_2O_3, and CuO nanoparticles at 300 K are illustrated in Table 1.

Nanoparticles are weighed with high precision using an electronic balance, and nanofluids are produced under vacuum conditions using a vacuum device to avoid contamination and oxidation of nanoparticles. The nanoparticles were stirred for 20 min using a magnetic stirrer and a hot plate at a temperature of 250°C after magnetic stirring. The nanoparticles remain agglomerated and in stable suspension using the model MTI Corporation.

3.4 Field emission scanning electron microscopy (FESEM) analysis

FESEM micrographs of nanofluid analysis after sonication for solutions of different initial concentrations of NiO, Al_2O_3,

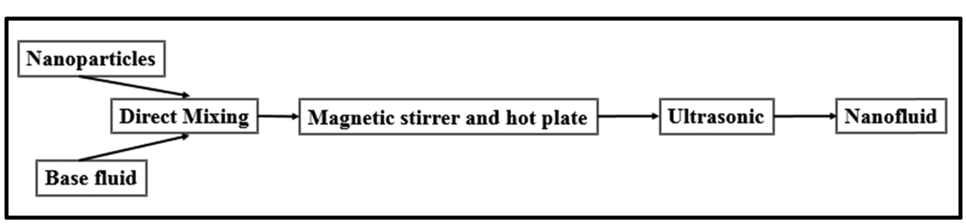

Figure 3: Two-step preparation process of nanofluids.

Table 1: Pure water and nanofluids properties at 300 K [23]

Fluid at 300 K	Thermal conductivity (W/m K)	Density (kg/m^3)	Heat capacity (J/kg K)
Pure water	0.6103	996.5	4,181
NiO	4.5	6,670	425
Al_2O_3	17.7	6,510	525
CuO	33.1	3,965	569

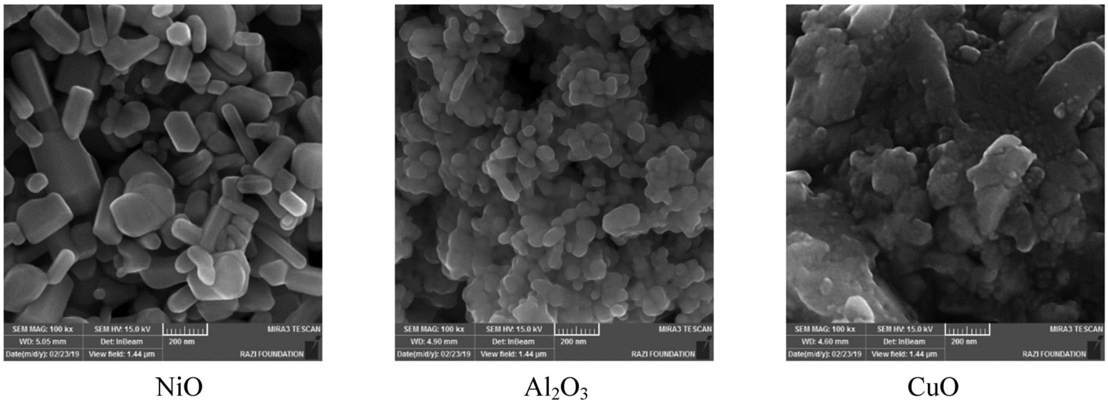

Figure 4: FESEM of NiO, Al_2O_3, and CuO.

and CuO at 200 nm are shown in Figure 4. This number provides the effect of concentration on particle formation and deposition mechanisms. The photo scale is 200 nm and it can be noted that the particles are less than 100 nm.

3.5 Analysis the results

Focusing collectors have different thermal behavior than flat-plate collectors due to the different shapes of the receivers. As a result, the temperature and conductivity of the focused collector are advanced, and the radiation flux across the receiver is less uniform. The following equations can be used to determine the thermal performance of a conical collector [11].

$$Q_u = A_r[C(\rho\alpha\gamma)H_b - U_L(T - T_a) - \varepsilon\sigma(T^4 - T_a{}^4), \quad (5)$$

which is then modified as in ref. [11],

$$Q_u = F_R A_a[S - (A_r/A_a)U_L(T_{fi} - T_a)]. \quad (6)$$

The actual or useful heat Q_u equals the sensible heat removed by the fluid through the receiver and can be calculated by using equation (7) as mentioned in ref. [12].

$$Q_u = mC_p(T_{fo} - T_{fi}). \quad (7)$$

The efficiency factor of the collector considered from the equation [12] is

$$F' = U_O/U_L. \quad (8)$$

The factor of heat removal is given by [12]

$$F_R = mC_P/A_f U_L[1 - e(A_f U_L F/mC_P)], \quad (9)$$

where U_L is the loss coefficient and U_o is the overall heat transfer coefficient which can be computed using equation (10), and the wind force is also occupied as [12]

$$U_O = [1/U_L + D_O/h_i D_i + D_O \ln(D_O/D_i)/2k]^{-1}, \quad (10)$$

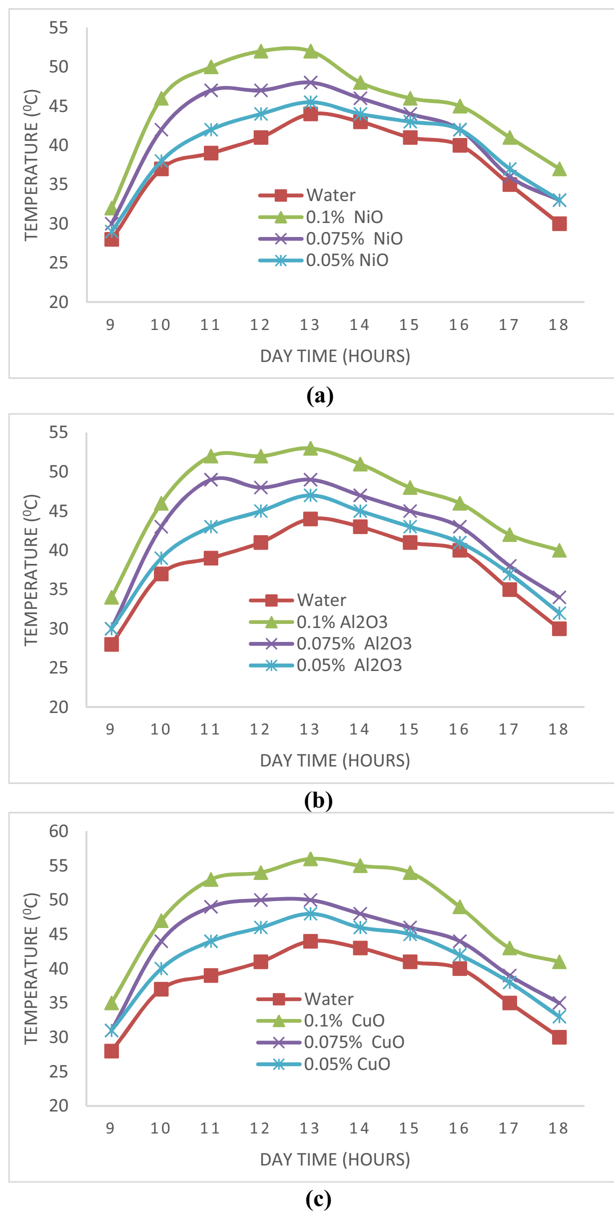

Figure 5: Comparison of temperature for (a) NiO nanofluid, (b) Al_2O_3 nanofluid, and (c) CuO nanofluid at different concentrations.

where $U_o = 5\,\mathrm{W/m^2K}$ is the average overall heat transfer coefficient, whereas $U_L = 5.4\,\mathrm{W/m^2K}$ is the average loss coefficient. The collector's aperture area A_a is $0.9675\,\mathrm{m^2}$, whereas the recovering area A_r is $0.12011\,\mathrm{m^2}$. This conical collector's concentration ratio is 8.091.

The collector efficiency is calculated as

$$\eta = Q_u / H_b A_a. \tag{11}$$

4 Results and discussion

4.1 Temperature distribution results

The temperature of water and other nanofluids increased throughout the day, as shown in Figure 5. The temperature is measured between 9:00 am and 6:00 pm on September 10, 2021, at Kufa, Iraq, latitude 32.05 and longitude 44.37.

By comparing the results of three nanofluids of NiO, Al_2O_3, and CuO, with different amount of concentrations (0.05, 0.075, and 0.1%), it can be shown from Figure 5 that the effect of these types of nanoparticles has a positive impact compared to each concentration of base fluid (water). Experiments were performed with water and nanofluids containing different percentages of NiO, Al_2O_3, and CuO nanoparticles, such as 0.05, 0.075, and 0.1% by volume. The temperature rise was measured throughout the day and the difference was shown. Increasing the concentration of similar nanofluids increases the overall temperature of the day as the overall fluid thermal conductivity increases. The graph shows that the average temperature increases with the increase the nanoparticle concentration. The highest temperatures of NiO, Al_2O_3, and CuO nanoparticles at 0.1% concentration were 51.75, 52.5, and 56.5°C, respectively, while the lowest temperatures were 44.7, 45.5 and 47.3°C respectively. Figure 6 explains the behavior of different nanofluids at 0.1%. It can be concluded that CuO has the best results for increasing the temperature profile as the thermal conductivity of the whole fluid increases.

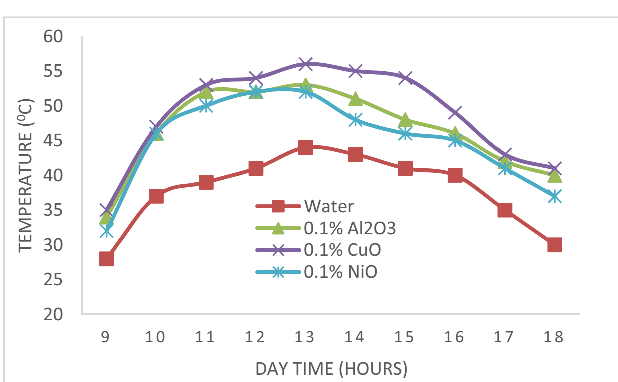

Figure 6: Comparison of temperature for nanofluids at a concentration of 0.1%.

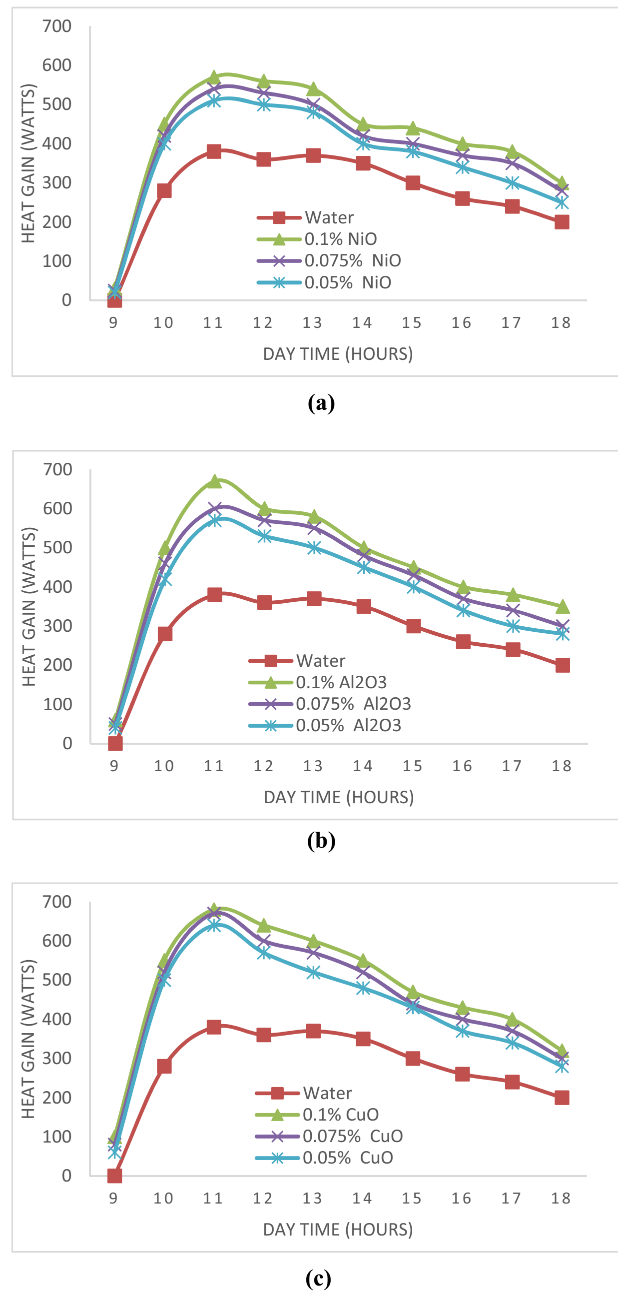

Figure 7: Comparison of heat gain for (a) NiO nanofluid, (b) Al_2O_3 nanofluid, and (c) CuO nanofluid at different concentrations.

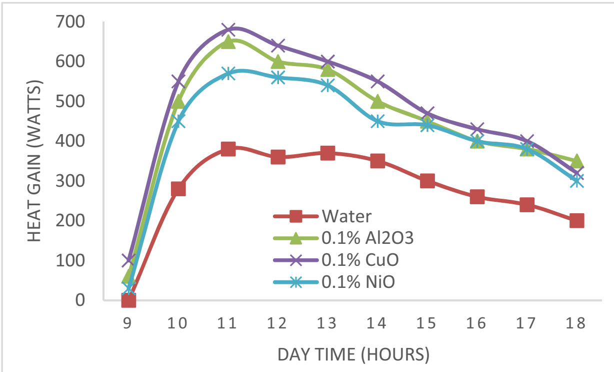

Figure 8: Comparison of heat gain for nanofluids at a concentration of 0.1%.

4.2 Heat gain results

The results demonstrate that temperature increment and thermal gain are achieved by using nanofluids and different amounts of nanoparticle concentration. Figure 7 shows the heat collected by water and nanofluids. The heat gain could be higher for the above experiments if off-the-shelf nanofluids were used instead of mechanical stirring. The maximum heat gains for NiO, Al_2O_3, and CuO nanoparticles at 0.1% concentration are 570, 662, and 680 W, respectively, while the lowest heat gains are 510, 570, and 640 W for NiO, Al_2O_3, and CuO nanoparticles at a concentration of 0.05%. Also, the thermal gain of CuO nanoparticles is better than that of other nanoparticles, and Al_2O_3 has a good enhancement effect compared with NiO nanoparticles with the same concentration of 0.1%, as shown in Figure 8.

5 Conclusion

According to several reviews on nanofluids in solar collectors, nanofluids work best in increasing heat transfer in solar collectors compared to water-based solar collectors. In addition, the nanofluids in solar collectors have been used to increase efficiency by up to 7% compared to water.

The study found that adding trace amounts of nanoparticles to a base liquid (H_2O) greatly improved its absorption capacity. This is still the case, although thermal efficiency has increased and outlet temperatures have increased. Depending on the application, numerous operating factors (collector shape, concentration ratio, and fluid properties) can also be modified to obtain the chosen outlet temperature. Nanofluids have better heat transfer properties than ordinary water. The heat transfer rate is affected directly by the nanoparticle concentration for all volume percentages. Heat transfer is enhanced with increasing nanoparticle concentration. CuO nanofluids have better heat transfer ability than Al_2O_3 or NiO-based nanofluids.

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Conflict of interest: Authors state no conflict of interest.

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